



# **Onboard Science Data Compression: Technology Development and Status at GSFC**

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# CONTENT

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- *Lossless Compression:*

- **Development History**
- **Performance**
- **Status**

- *High Performance Compression:*

- **Requirement for Space Applications**
- **GSFC/NASA Technique**
- **CCSDS WG Selection**
- **Performance**
- **Technology Status**

- *Results on Simulated AIRS Data*



# LOSSLESS DATA COMPRESSION DEVELOPMENT HISTORY



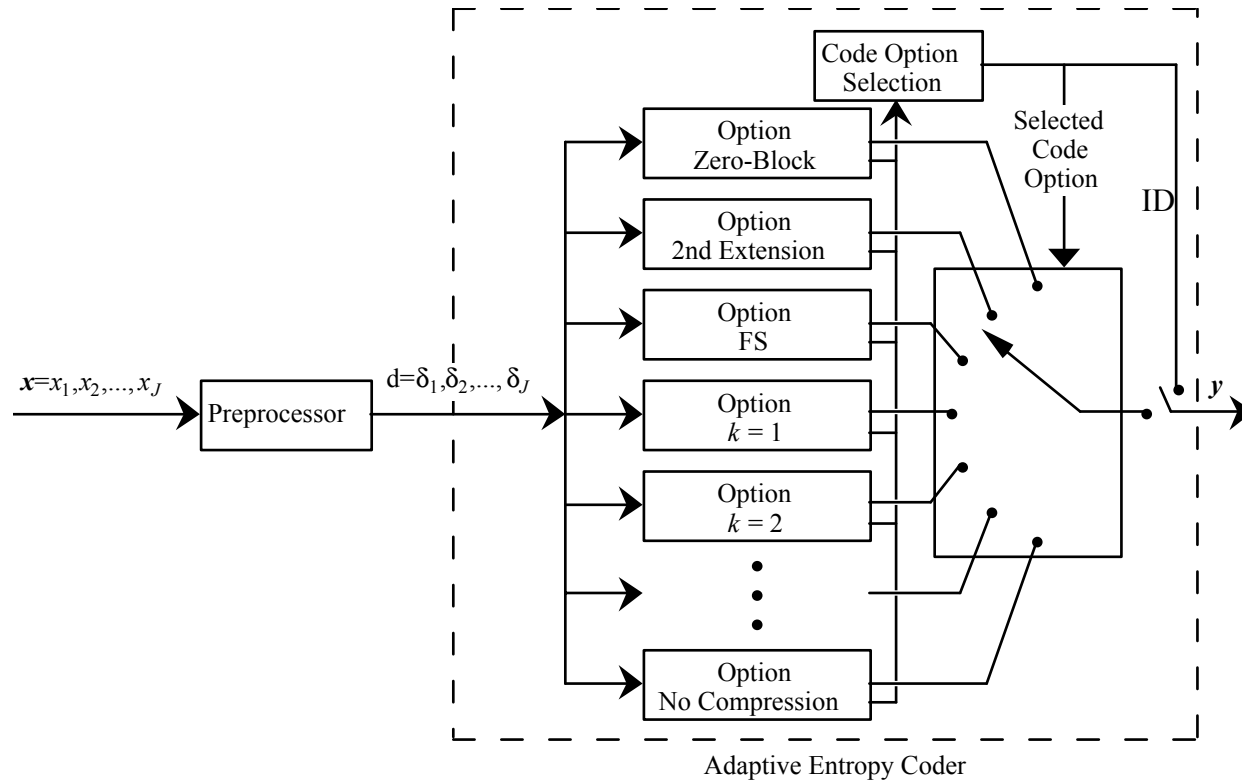
## *History*

- **1988-1989: requirements established**
  - Applicable to various instruments and missions
  - Adaptive to statistics and easily implementable with low memory, high speed
  - Easily interfaced with packet data system w/o performance penalty
- **1989-1990:**
  - algorithm comparison (Rice, LZW, arithmetic, Huffman)
  - Rice algorithm selected, added enhancement at low entropy
  - mathematical proof established
- **1990-1993: ASIC development, S/W by-product**
- **1994-1995: algorithm submitted to CCSDS as candidate**
- **1997: algorithm became CCSDS recommendation, Blue Book and Green Book published. First flight-validation on COBRA/DOE**
- **~present: project support**



# LOSSLESS DATA COMPRESSION

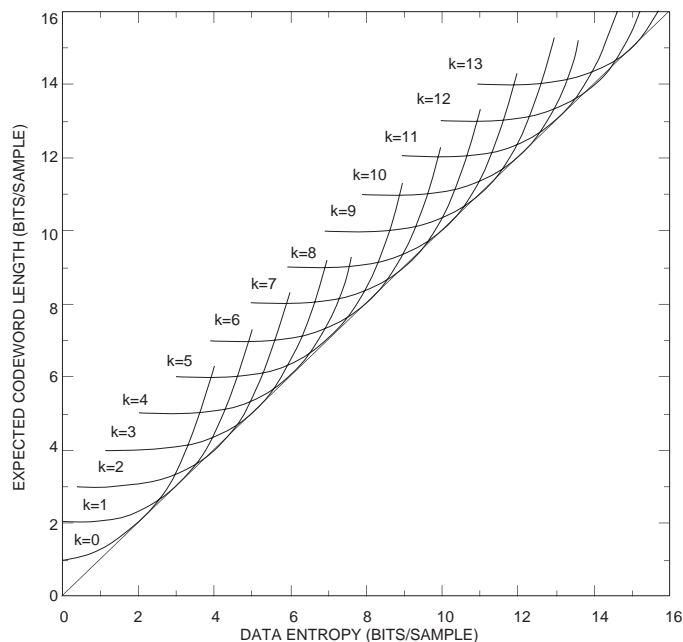
## Algorithm Architecture



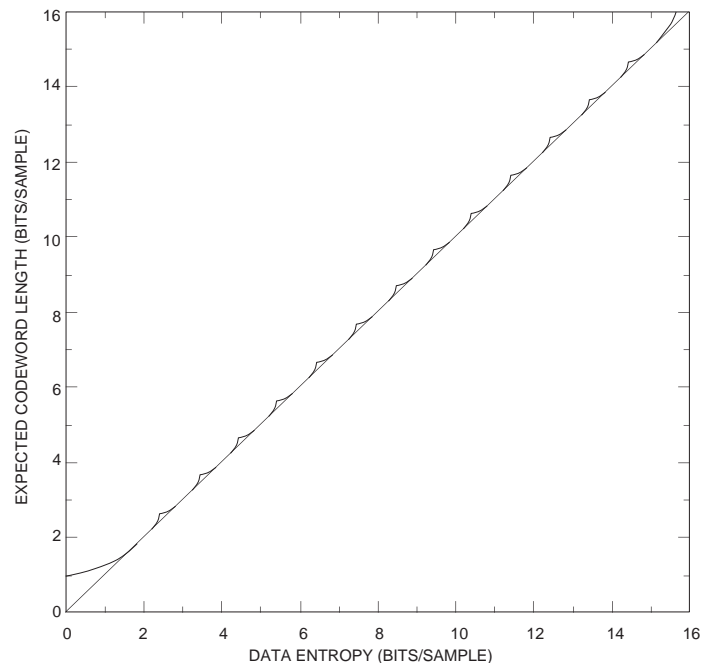
## Rice Algorithm Architecture



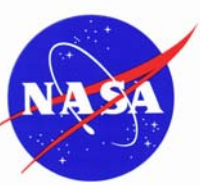
# E-Rice Algorithm Theoretical Performance on Data with Laplacian Model After De-correlation



**Performance Curve for Each Option**



**Overall Performance Curve**



# E\_Rice Algorithm Performance on Science Data Archive Applications



**Objective:** Compare performance of CCSDS lossless (*szip*), LZW (*compress*, *gzip*) and arithmetic coding(*az*) techniques on EOSDIS data sets, with two measurements: **Compression Ratio (CR)** and **speed**.

**Test Data Source:** MAS, TRMM, AVHRR, TOVS, ASTER, SeaWifs, TOMS in a total **data volume** of 930 Mbytes.

**Data Format:** Level 1B, 2,3,4, Grid, Swath, byte, int\*2, real\*4

## Results Summary: (on Sun Sparc20)

	<i>szip</i>	<i>gzip</i>	<i>compress</i>	<i>az</i>
<b>CR</b>	3.24	2.44	2.06	2.38
<b>Time(compress,Seconds)</b>	353	8112	1973	10516
<b>Time(decompress,Seconds)</b>	394	1264	790	7341



# NASA LOSSLESS DATA COMPRESSION TECHNOLOGY



## USERS

<b>Mission</b>	<b>Launch</b>	<b>Lead Agency</b>	<b>Implementation</b>
Mars Observer	09/92	NASA/JPL	SW
SERTS-96 (Sounding Rocket)	11/96	NASA/GSFC	HW
Mars-96	11/96	RSA	SW
COBRA	/97	DOE	HW
LEWIS/SSTI	08/97	NASA/HQ	HW
CASSINI Cosmic Dust Analyzer (CDA)	10/97	NASA/JPL	SW upload after launch
SERTS-97	11/97	NASA/GSFC	HW
SWAS/SMEX-3	01/99	NASA/GSFC	SW
EO-1	12/99	NASA/GSFC	HW
KOMPSAT-1	/99	KARI	HW
IMAGE/MIDEX-01	02/00	NASA/JPL	SW
THEMIS/Mars Odyssey	04/01	NASA/JPL	HW
VCL/ESSP-01	/01	NASA/GSFC	HW
MAP/MIDEX-02	07/01	NASA/GSFC	SW
SIRTF	12/01	NASA/JPL	?
EOS CHEM-1/AURA	12/02	NASA/GSFC	HW
ROSETTA	01/03	ESA	HW
Space-Based Infrared Sys	Multiple	DOD	HW
INTEGRAL SPI	2002	ESA	SW in ADA
<b>HDF4/5</b>	2003/5	NASA/NCSA	SW release/ground archive
MESSENGER(MLA)	2004/5	NASA	SW
GIFTS/EO-3	200?	NASA/LaRC	HW
PICARD	2005	CNES	SW on DSP
NPP	200?	NOAA/NASA	HW
GOES/ABI	200?	NOAA/NASA	HW
JWST	200?	NASA	HW
GPM	200?	NASA/GSFC	SW



# LOSSLESS DATA COMPRESSION FOR SPACE APPLICATIONS

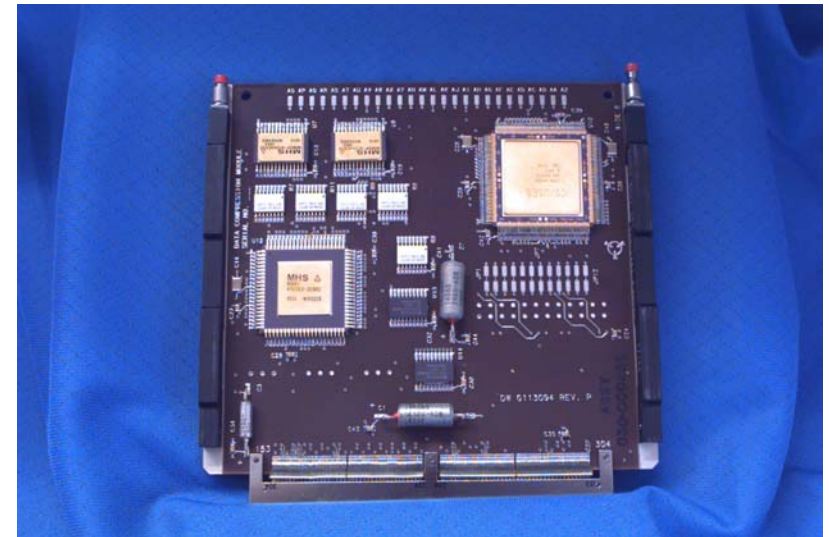


## *Benefits for NASA Missions*

- Reduces bandwidth requirement, onboard storage or station contact time
- Reduces ground archive volume with savings in \$\$M

## *Technology Features*

- Algorithm adopted as CCSDS recommendation
- Works well with large data quantization range and packet data system without penalty on performance
- ASIC offers real-time operation  $> 40$  Msamples/sec in space environment
  - Compresses faster and better than commercial techniques



Lossless Compression Board

## *Users*

COBRA/DOE, SWAS/SMEX, MAP/MIDEX, EOS-CHEM, KOMPSAT, IMAGE, CASSINI, INTEGRAL, SERTS, SBIRS/DOD, MARS ODYSSEY, NPP, EO-3, MLA/MESSENGER, ABI/GOES, EOSDIS(HDF), GPM, NPOES, JWST.

## *Information*

[http://www.ccsds.org/ccsds/ccsds\\_document\\_access.html](http://www.ccsds.org/ccsds/ccsds_document_access.html)

<http://www.cambr.uidaho.edu>



# CONTENT

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- *Lossless Compression:*

- **Development History & Requirement**
- **Performance**
- **Status Summary**

- *High Performance Compression:*

- **Requirement for Space Applications**
- **GSFC/NASA Technique**
- **CCSDS WG Selection**
- **Performance**
- **Technology Status**

- *Conclusion*



# HIGH PERFORMANCE DATA COMPRESSION

## requirement for space applications



Requirements established by Consultative Committee for Space Data Systems (CCSDS) Compression Working Group in 1998:

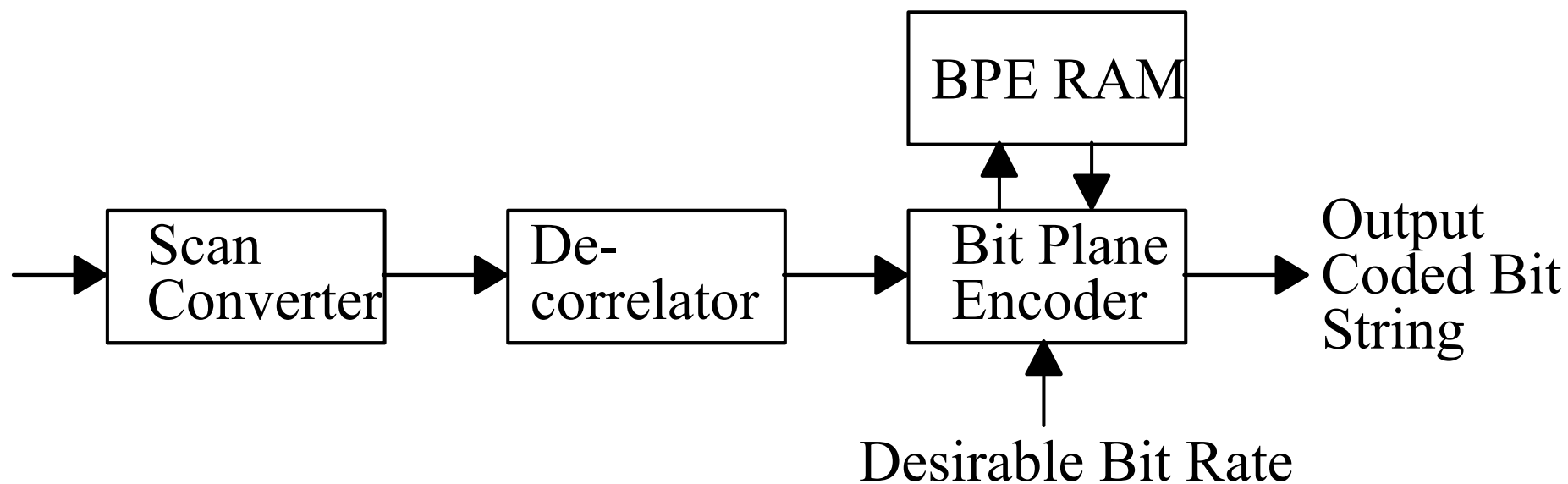
- Offer “Royalty free” algorithm
- Process both non-frame based (push broom) and frame based input source data.
- Offer adjustable data rate.
- Work with large source quantization ranges up to 16 bit-per-pixel
- Offer real-time processing  $\geq 20$  Msamples/sec,  
at  $\leq 1$  watt/Msamples/sec.

The power consumption includes all buffering and support electronics.

- Require minimum ground interaction during operation.
- Allow packetization for error containment.
- Allow progressive transmission/Decoding (optional)



# GSFC/NASA TECHNIQUE



De-correlator: Discrete Cosine Transform, Lapped Transform, Wavelet Transform

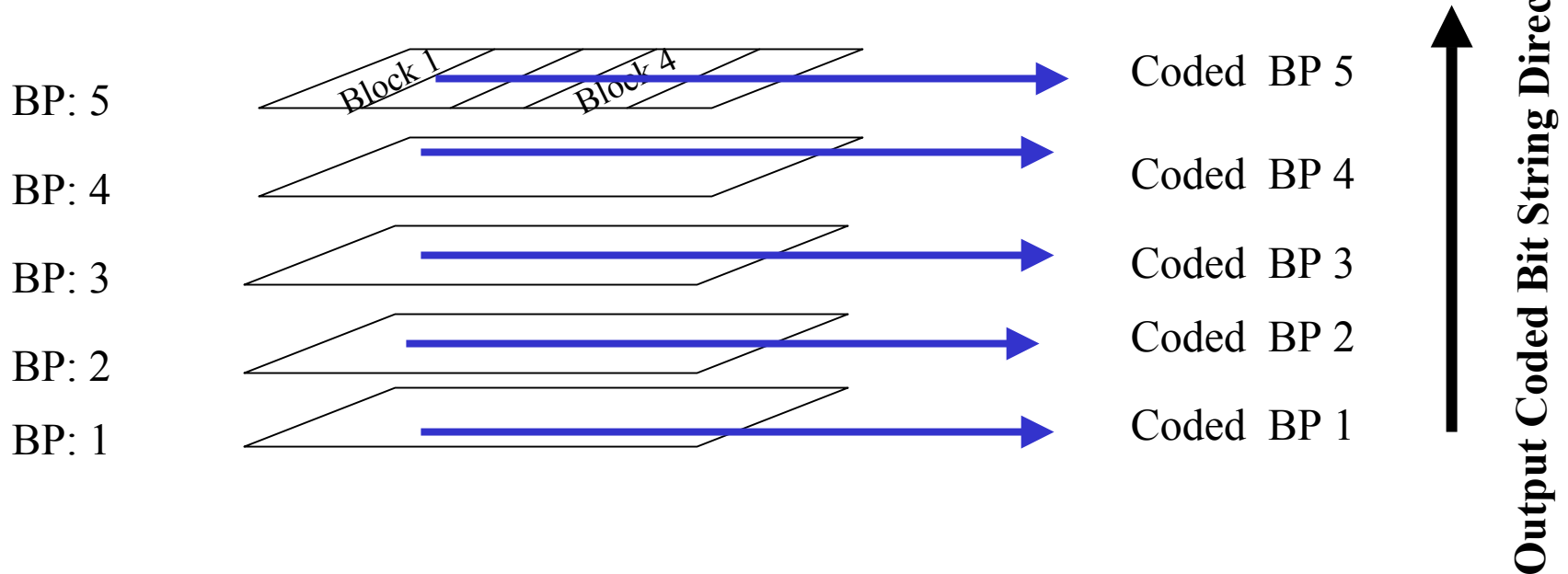


# BIT PLANE ENCODER



## Multiple Bit Planes

**Transformed Coefficients in Bit Planes:**

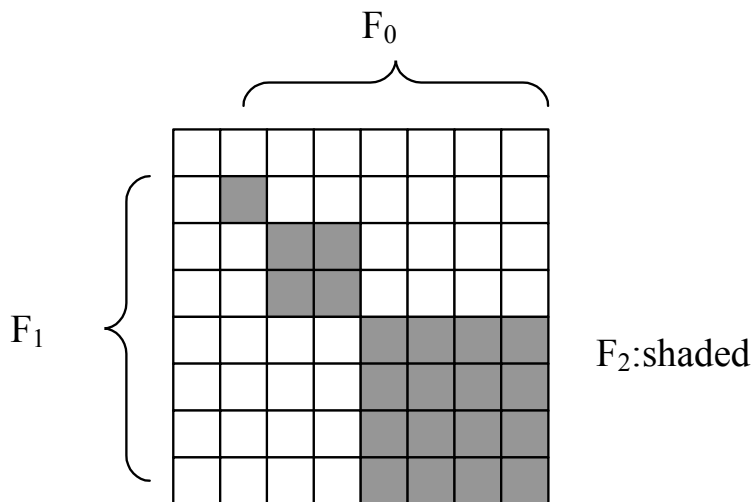




# BIT PLANE ENCODER



## Blocks on Bit Plane



Scanning on each bit plane

Direction:  $F_0 \Rightarrow F_1 \Rightarrow F_2$

Coding: 3 main levels/block

Output: embedded bit string

$\Rightarrow$  progressive decoding

- \* No look up table
- \*  $> 20$  Msamples/sec
- \* Radiation Tolerant implementation
- \* Progressive decoding for quick-look



# CCSDS WG SELECTION



CCSDS Image Data Compression Working Group (Sub-Panel 1C) has been trying to select an algorithm as recommendation for space implementation.

After nearly 5 years of work on evaluating performance, implementation issues, impact on science it finally made a decision (April, 03) to adopt:

- Discrete Wavelet Transform: 9/7 floating and 9/7 (or 5/3) integer
- Bit Plane Encoder

With integer wavelet, the scheme will provide from high compression ratio, to visually lossless and to mathematically lossless performance.

Agency review on Red Book will commence after October 03, with Blue Book/Green Book and S/W projected July 2004.



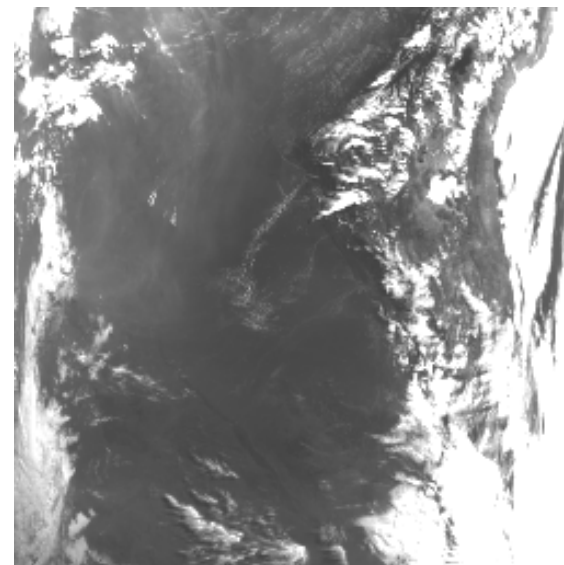
# TEST IMAGES



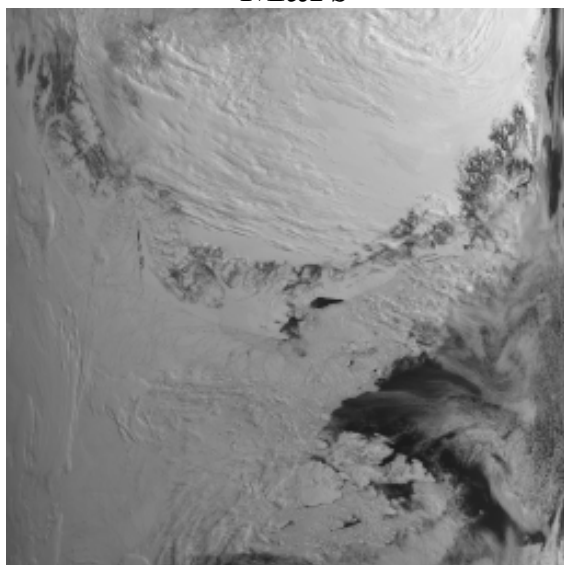
**Mars**



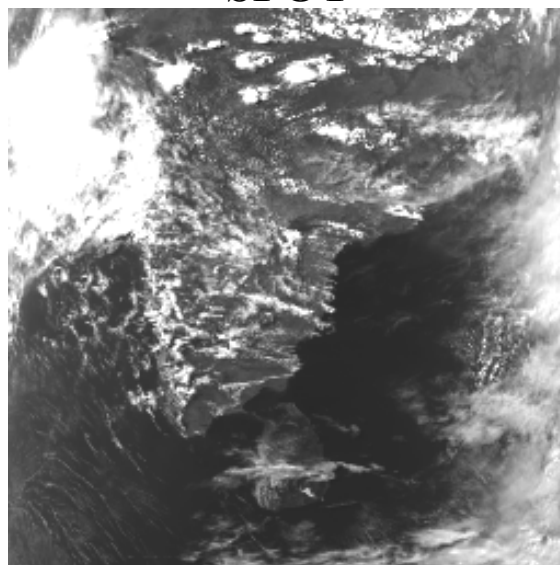
**SPOT**



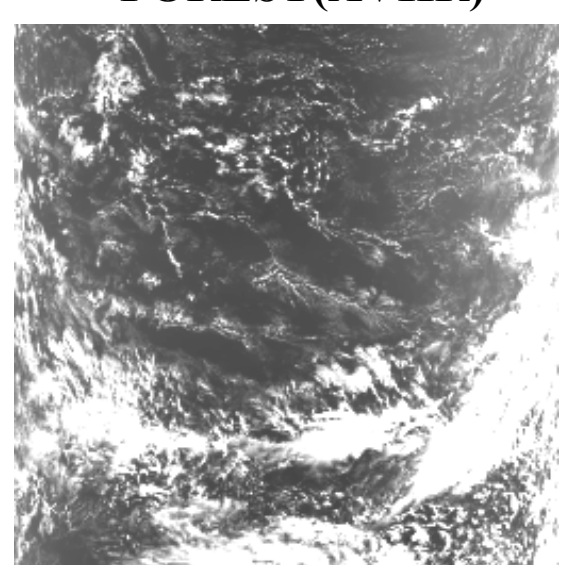
**FOREST(AVHR)**



**ICE(AVHR)**



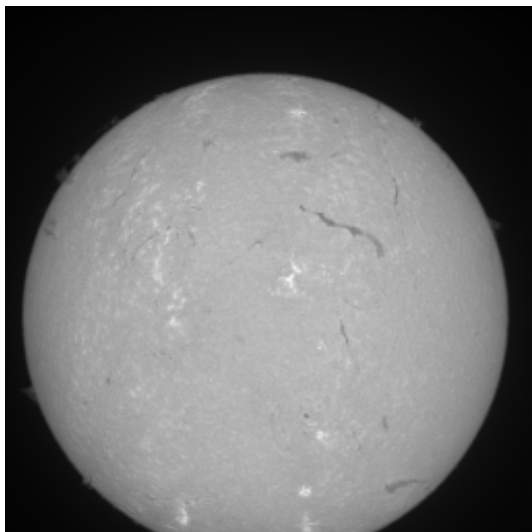
**INDIA(AVHR)**



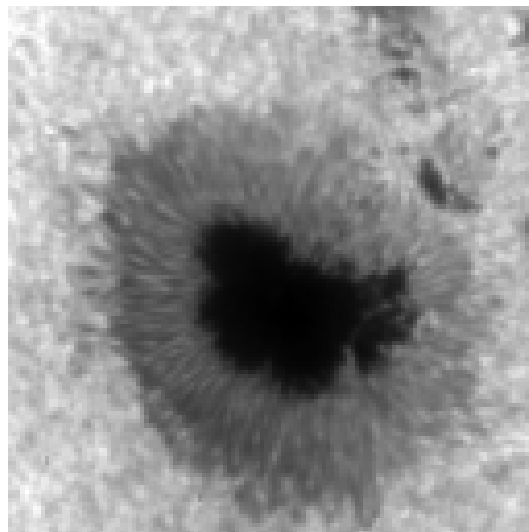
**OCEAN(AVHR)**



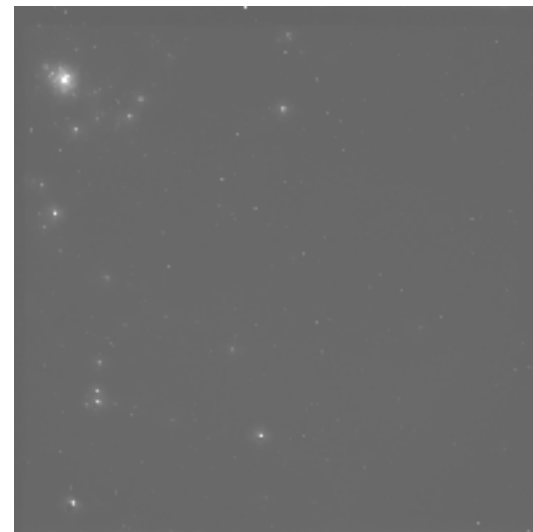
# TEST IMAGES



**SOLAR**



**SUNSPOT**



**WFPC**



**FOC**

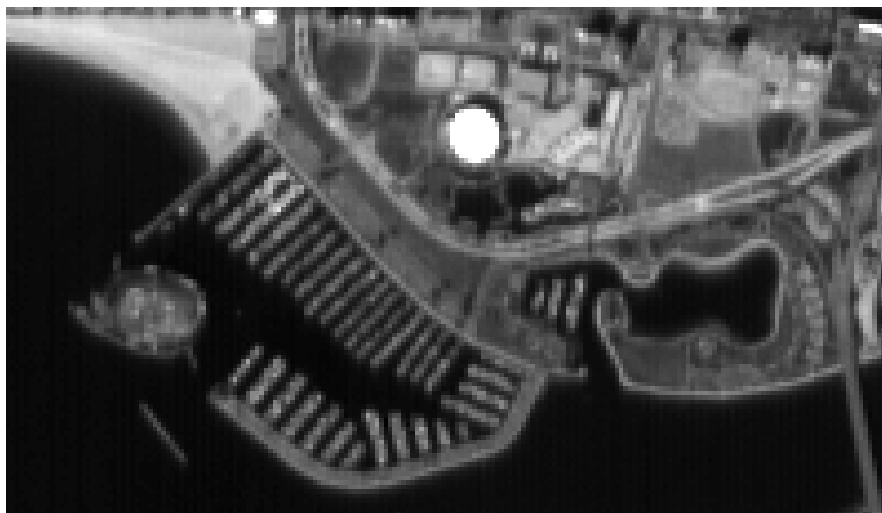


**SAR**

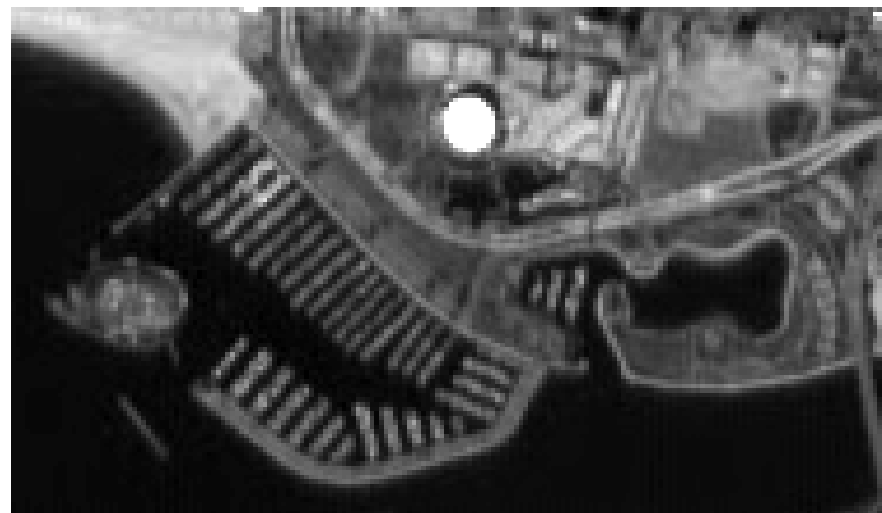


# PERFORMANCE

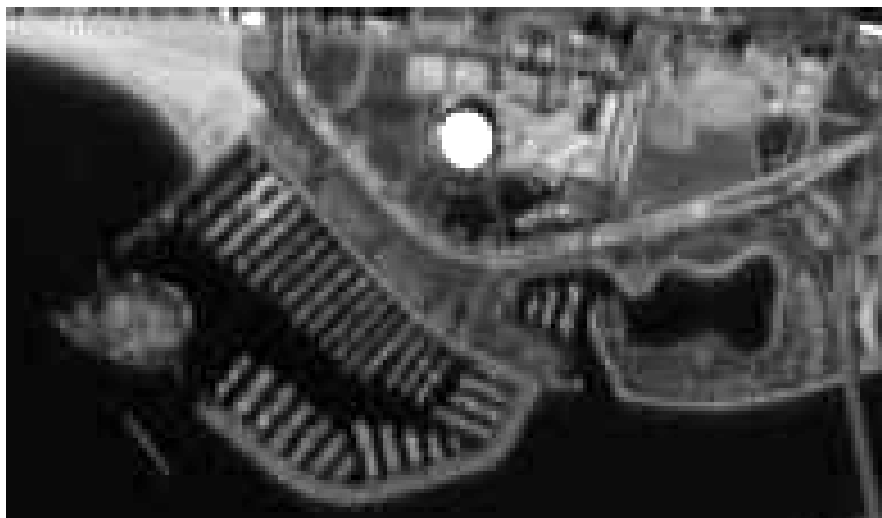
## Visual Evaluation Performed at 1.0 bpp



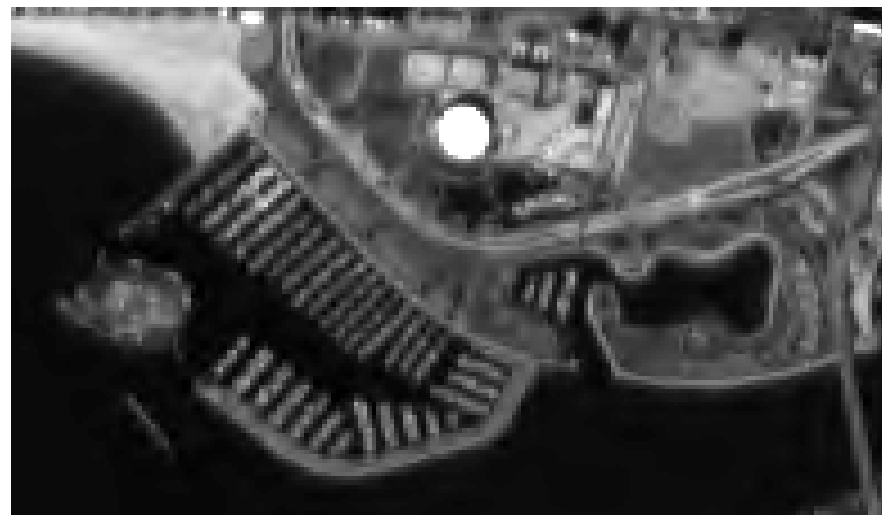
**Original**



**2DMLT**



**JPEG**

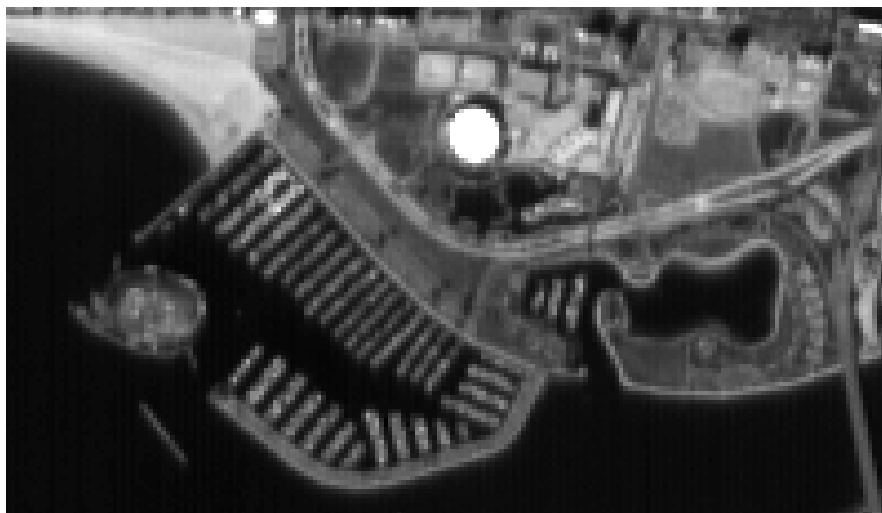


**JPEG2000**

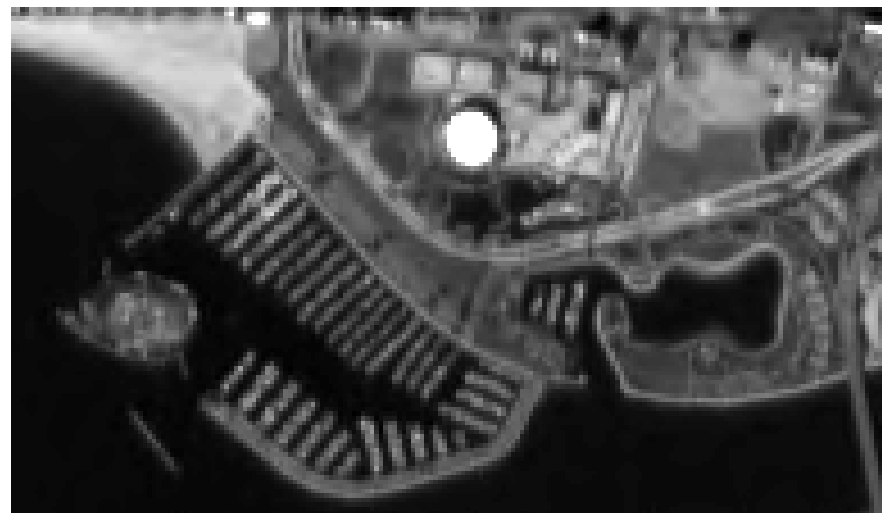


# PERFORMANCE

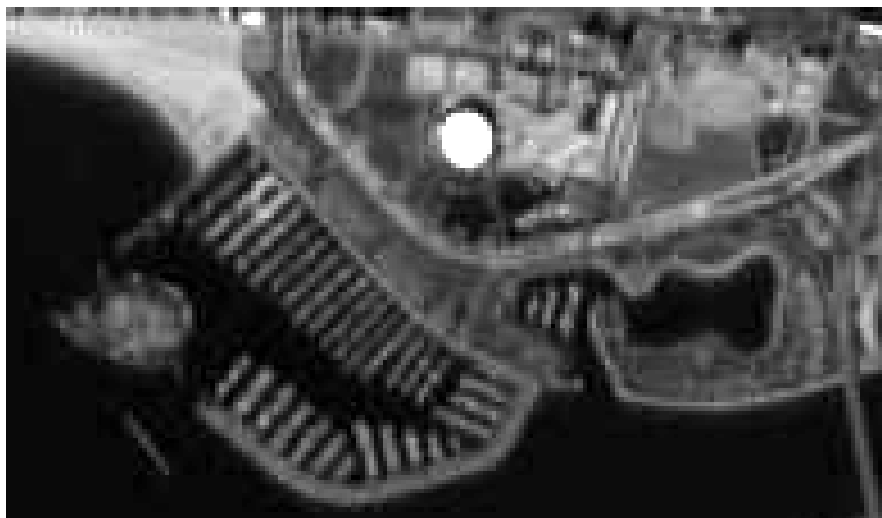
## Visual Evaluation Performed at 1.0 bpp



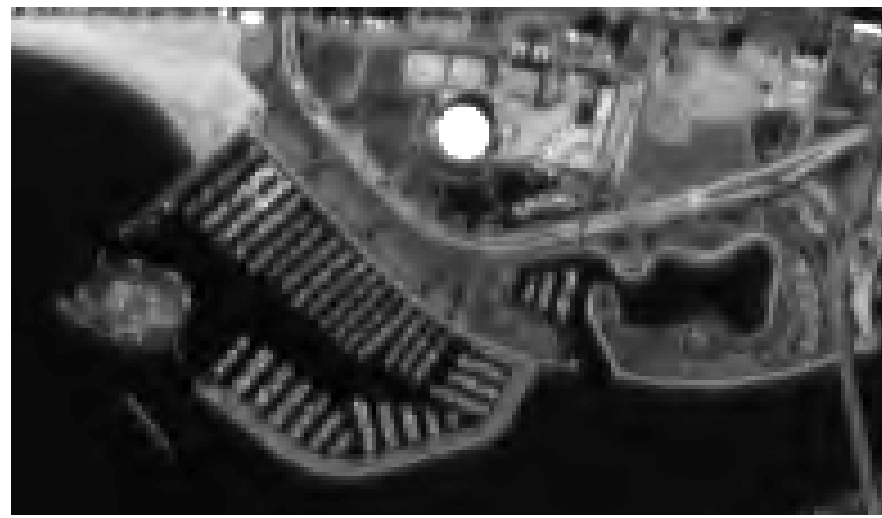
**Original**



**CCSDS**



**JPEG**

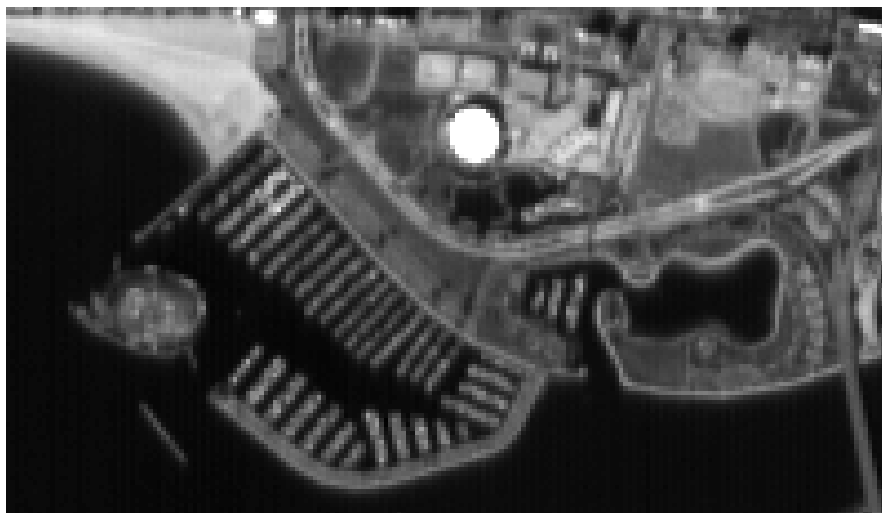


**JPEG2000**



# PERFORMANCE

## Visual Evaluation Performed at 0.5 bpp



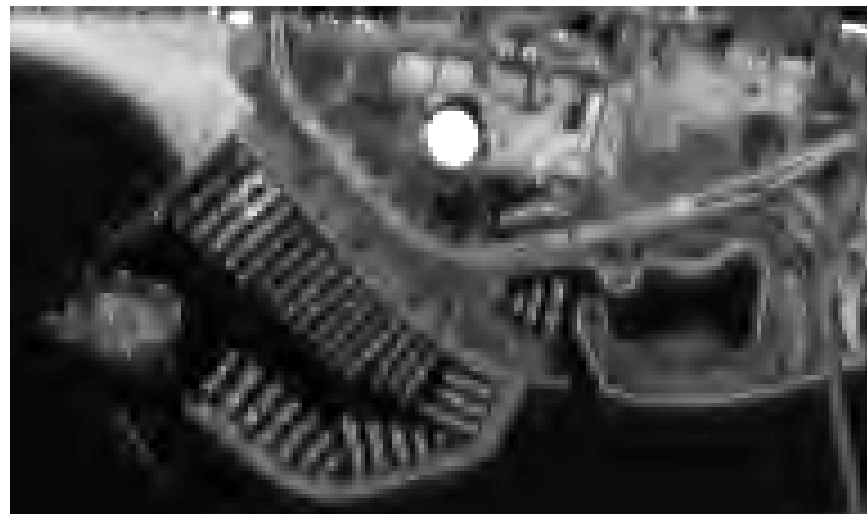
**Original**



**CCSDS**



**JPEG**



**JPEG2000**



# PERFORMANCE

## Visual Evaluation Performed at 1.0 bpp



**Original**



**CCSDS**



**JPEG**



**JPEG2000**



# PERFORMANCE

## Visual Evaluation Performed at 0.5 bpp



**Original**



**CCSDS**



**JPEG**



**JPEG2000**



# TECHNOLOGY STATUS



- **Earlier version on Lewis for Hyper-Spectral-Imager (data cube compression, '97)**
- **DCT/EDCT RT chip fabricated (upto 16-bit input), tested at 35 Msamples/sec**
- **2D DWT chip planned 2004-5 design/fabrication**
- **Bit Plane Encoder chip under design ==> 2004 fabrication**
- **System power estimated at 0.36 watt/Mpixel/sec**
- **Software simulation performed on various types of images**
- **Performance impact on science product under study**
  - sea surface temperature --on NOAA-14 data,  
mean error < 0.01k from 0.25 - 2 bpp, 5/00
  - cloud detection using MODIS algorithm
  - Retrieval for sounder (HES) data (GOES-R)

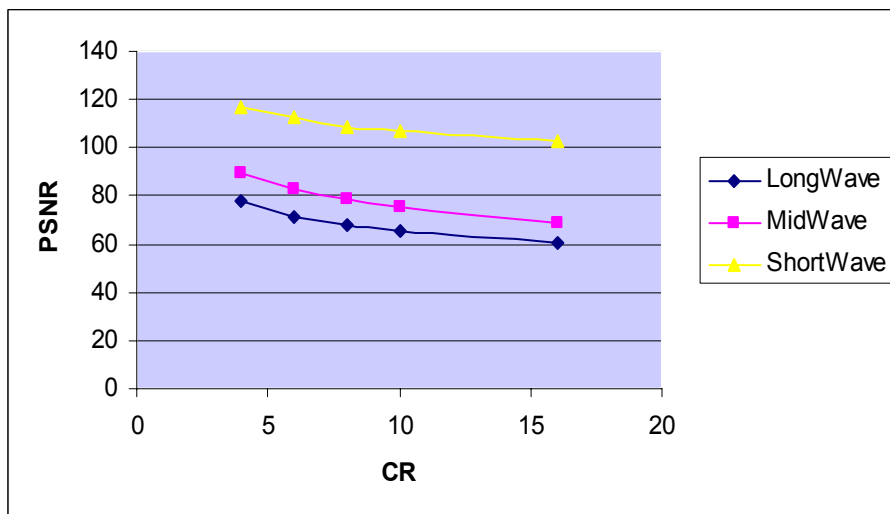


# Results on AIRS Data

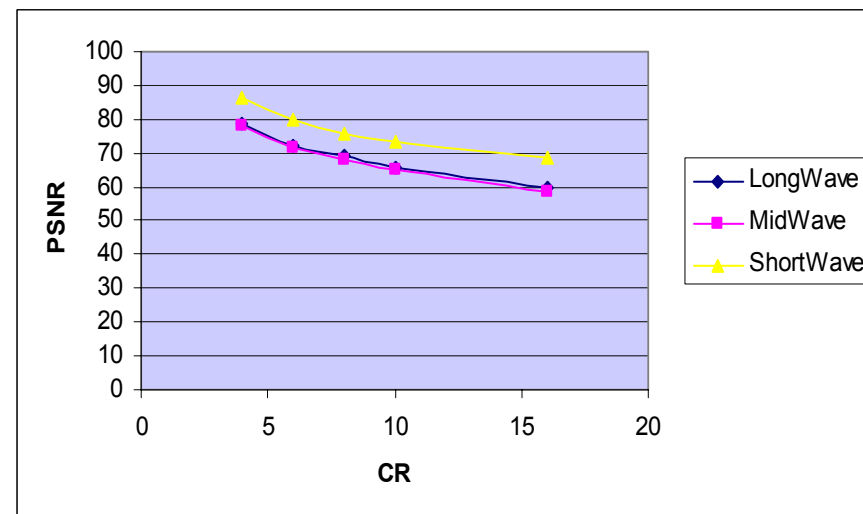
**Lossless Compression (CCSDS): CR=16./bpp, using spectral prediction**

	LongWave	MidWave	ShortWave
Radiance	1.95	2.77	2.01
BrightnessTemp	2.02	2.18	2.32

**Lossy Compression (LT+BPE): CR=16./bpp, processing on spectral-spatial domain**



Radiance



Brightness Temp